EUROPEAN
COMMISSION

Community research

A Vision for
Photovoltaic
Technology

EUR 21242

EUROPEAN COMMISSION
Directorate-General for Research
Directorate J – Energy
Unit J-3 – New and Renewable Energy Sources
Contact: Georges Deschamps
Office CDMA 5-169
B-1049 Brussels
E-mail: georges.deschamps@cec.eu.int
Helpline: rtd-energy@cec.eu.int
Internet: http://europa.eu.int/comm/research/energy/index_en.htm

We would like to thank the following companies and institutes
that have given us permission to use their photos:

BP Solar, Isofotón, Q-Cells, Shell Solar

A great deal of additional information on the European Union is available on the Internet.
It can be accessed through the Europa server (http://europa.eu.int).

Cataloguing data can be found at the end of this publication.

Luxembourg: Office for Official Publications of the European Communities, 2005

ISBN 92-894-8004-1

Printed in Belgium

PRINTED ON WHITE CHLORINE-FREE PAPER

A Vision for
Photovoltaic Technology

Report by the
Photovoltaic Technology
Research Advisory Council
(PV-TRAC)

2005

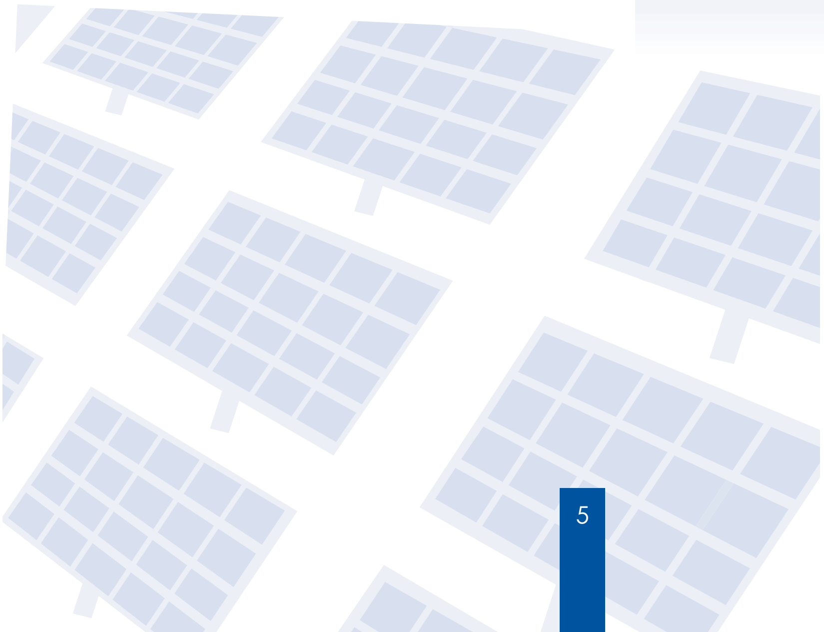
Directorate-General for Research
Sustainable Energy Systems

EUR 21242

PV-TRAC MEMBERS

Emiliano PEREZAGUA ***Chairperson***	ISOFOTON Chief Operations Officer
François DEMARCQ ***Vice-Chairperson***	ADEME General Manager
Zhores I. ALFEROV	Ioffe Physico-Technical Institute Vice-President of the Russian Academy of Sciences *Physics NOBEL Laureate 2000*
Viacheslav ANDREEV	Ioffe Physico-Technical Institute Head of Laboratory
Jean-Louis BAL	ADEME Renewable Energies Director
Karen DE SEGUNDO	Shell International Renewables B.V. CEO
Bernhard DIMMLER	Würth Solar GmbH & Co. KG Managing Director
Adolf GOETZBERGER	Fraunhofer Institute for Solar Energy Systems Former director
Carlos ITOIZ BEUNZA	Energía Hidroeléctrica de Navarra (EHN) Assistant CEO
Witold ŁOJKOWSKI	High Pressure Research Centre, Polish Academy of Sciences Associate Professor
Stefan NOWAK	NET Nowak Energy & Technology Ltd Managing Director Chairman IEA-PVPS
Wim SINKE	Energy Research Centre of the Netherlands (ECN) Senior staff member Solar Energy
Peter van der VLEUTEN	Free Energy International BV President
Ronald van ZOLINGEN	Shell Solar Senior Business Advisor
PV-TRAC Secretary	European Commission, Helen Sutcliffe

Photovoltaics literally means light-electricity: **photo** comes from the Greek *phos*, meaning light, and **volt** from the Italian scientist *Alessandro Volta*; a pioneer in the study of electricity. This technology, originally developed for space applications in the 1950s, has many advantages: it is modular, clean, easy to maintain, and can be installed almost anywhere to suit the needs of the user. The electricity produced can be used directly, stored locally or fed into an existing electricity grid.



FOREWORD

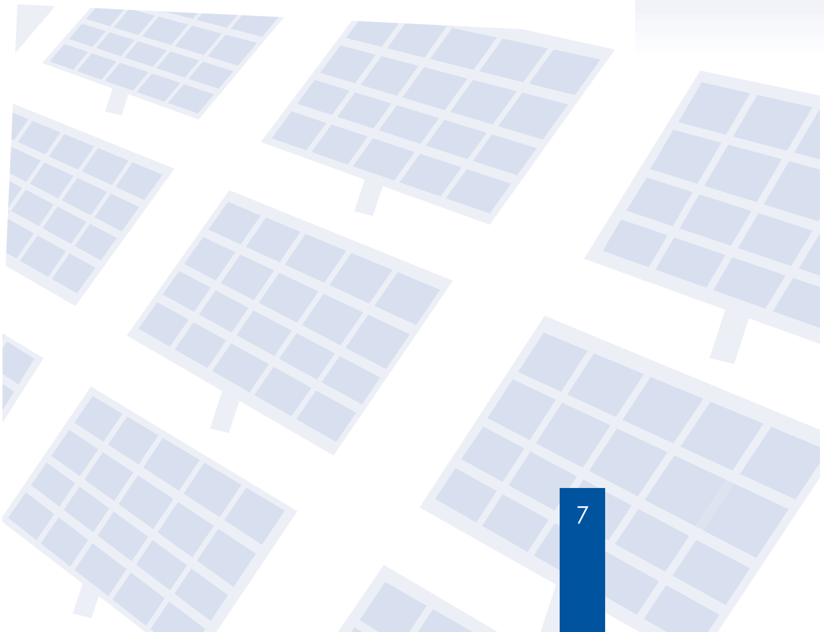
Photovoltaic technology converts the sun's rays directly into electricity without moving parts or emitting pollutants. If its costs can be lowered, photovoltaic electricity could become a competitive source of energy. It would help combat the global threat of climate change and improve the security of the European Union's energy supply. This is still some time away, but it does require sustained research and development investment as from today.

In December 2003, the Photovoltaic Technology Research Advisory Council (PV-TRAC) was formed under the auspices of Loyola de Palacio and Philippe Busquin (the former European Commissioners for Energy & Transport and Research). The Council's vision report presents the current state of photovoltaics and looks ahead towards the year 2030. I note that photovoltaic electricity could become competitive with conventional utility peak power in southern Europe by 2010 and in most of Europe by 2030. By then photovoltaics could provide around 4% of electricity production worldwide.

The European Union has funded research on photovoltaics since the 1970s, contributing to major improvements of performance. Within the current research Framework Programme, the EU has supported some major initiatives aimed at reducing the cost of modules, developing new materials and promoting market penetration. Future efforts must build on past successes and be strengthened, in particular through increased and coordinated efforts from the research community, industry and all the other relevant stakeholders.

I fully agree with the recommendation of the PV-TRAC to establish a Photovoltaic Technology Platform. I wish it every success and would expect the activities of the Platform to accelerate the development of photovoltaic technologies, leading to greater energy sustainability in Europe and beyond. This is a clear example of how investing in knowledge can make our society and economy both prosperous and sustainable in the long run.

Janez Potočnik
Commissioner for Science and Research



EXECUTIVE SUMMARY

This vision report has been prepared by the Photovoltaic Technology Research Advisory Council (PV-TRAC), whose declared mission is to contribute to a rapid development of world-class, cost–competitive European photovoltaics (PV) for sustainable electricity production.

The report identifies the major technical and non-technical barriers to the uptake of the technology and outlines a strategic research agenda designed to ensure a breakthrough of PV and an increase in deployment in the Union and worldwide. The Council proposes the use of a European Technology Platform as a mechanism to implement the strategy and achieve the wider goals defined in the vision.

Photovoltaic technology permits the transformation of solar light directly into electricity. PV systems can deliver electrical energy to a specific appliance or to the electric grid. It has the potential to play an important role in the transition towards a sustainable energy supply system of the 21st century and to cover a significant share of the electricity needs of Europe. PV could contribute to the security of future energy supply, provide environmentally benign energy services and enhance economic and social welfare. Alongside other renewable energy technologies and energy efficiency, photovoltaics could become a key technology for the future.

The advantages of PV include:

- Complementarity with other energy sources, both traditional and renewable
- Flexibility in terms of implementation. PV systems can be integrated into consumer goods or into buildings, installed as separate mobile or non-mobile modules, or in central electricity generating stations
- Production of electricity without greenhouse gas emissions.

Even if recent years have seen the amount of electricity produced using PV increase rapidly year after year, it is still a small amount compared to other renewables such as wind or biomass. The major barrier preventing uptake in today’s market is the cost of PV, making the electricity produced too expensive for many applications. The PV industry needs to become more competitive and develop more efficient manufacturing processes and conversion devices. The regulatory framework can often hinder installation and further work on effective standardisation would yield many advantages. The present market perception of the technology is that it is for niche applications, and not for general use. Fully coordinated research efforts would result in overcoming some of these barriers, but additional actions are needed from all stakeholders if deployment is to take off.

The analysis performed by the Advisory Council shows that PV has the potential to deliver electricity on a large scale at a competitive cost. In 2030 PV could generate 4% electricity worldwide. However, the Council considered 2030 only as an intermediate milestone and stressed that PV would continue to grow steadily well beyond that date. It is envisaged that the technology will develop towards higher efficiency modules, cells and systems, with longer lifetimes and improved reliability, making use of new materials. Generation costs are expected to fall significantly, resulting in increased uptake and deployment both in industrialised markets and for non-grid applications in developing countries, thereby creating employment and exports. The PV market will be highly competitive, and ensuring European leadership in this high-tech sector will require well-coordinated, concentrated and long-term efforts.

In order to reach the PV vision, the Council advocates that a number of actions are taken, notably including the creation of a European PV Technology Platform. The PV Technology Platform is the preferred vehicle to mobilise and pursue PV-related initiatives, programmes and policies bringing together all relevant stakeholders from science, industry and policy areas. Implementation of the PV Platform will strongly increase the efficiency of the efforts currently under way and accelerate the development of the European PV sector. In particular, the Council recommends that the PV Technology Platform should:

- Implement the Strategic Research Agenda, in which the main PV research and technological development issues for the coming decade are addressed. To achieve the technology goals, enhanced research investment and continuity of effort are needed. PV research should be supported through both European and national funding mechanisms. The SRA should foster an interdisciplinary approach to the development of PV and cross-fertilisation from other rapidly developing fields.
- Strongly coordinate ongoing PV research activities in Europe with the help of a Mirror Group representing all the Member States. European and national programmes should be reviewed to ensure stronger co-operation.
- Facilitate the coherent implementation of deployment measures (incentives, industrial, environmental, social and education). Promote, as a transitional measure over the next decade, a coordinated regulatory framework that takes the specific aspects of PV into account. Encourage a sustained growth and the transition to a sustainable market and overcome barriers related to regulations, standards, safety and social acceptance. The platform together with the Mirror Group will provide a mechanism for consensus building in these areas.

- Foster joint initiatives between researchers, industry, Member States and the EU. Develop a robust communication plan, as part of a continuous dialogue involving a broad range of stakeholders.
- Optimise the use of instruments and resources to encourage investment in research and innovation to capitalise on Europe's investments in the PV sector. Support export and trade in PV products in the global market place.
- Strengthen the relationships with developing countries in order to bring affordable electricity services to the population of these countries.

The challenge remains for the recommendations given by the PV-TRAC to be properly developed and implemented. It is now the responsibility of all stakeholders to acknowledge the long-term strategic nature of photovoltaic technologies and ensure that PV becomes a major element in the renewable energy future.

INTRODUCTION

Availability of clean, safe and affordable energy to all citizens in sufficient quantities is a prerequisite for a sustainable society. In addition, the world energy supply should be sustainable in itself, meaning that the use of finite fossil resources has to be gradually replaced by the application of renewable energy technologies and that greenhouse gas emissions have to be decreased substantially. To ensure the security and sustainability of future energy supply in Europe, we need diversified and renewable energy sources. The increasing share of renewable energy is a necessary ingredient of greenhouse gas mitigation policies, along with a strong requirement to improve energy efficiency. Changing living standards and patterns to sustainable ones and ensuring the protection of the environment are now recognized as major policy goals.

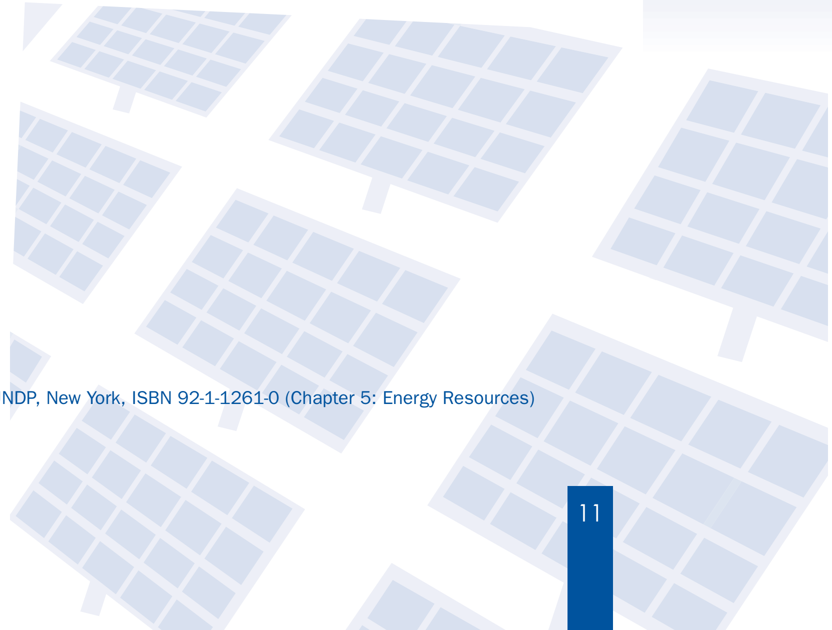
Presently almost one-third of the world population does not have access to commercial energy (in particular, to an electricity grid), which seriously hinders development, is linked to poverty and causes a variety of health problems. In spite of the recent success of renewable energies in some areas, the growing global energy consumption still causes an increase in the consumption of fossil fuels and associated CO_2 emissions. This highlights the urgency to develop and implement renewable energy technologies that can be made available to all people in urban and rural areas and that can make a substantial contribution to the increasing energy demand.

There is general consensus that photovoltaic conversion of solar energy (PV) is such a technology. PV has the unique property that arrays can be built ranging from a few milliwatts up to a multi-megawatt installation. PV modules can be part of a consumer product, mounted on roofs of houses, integrated in a building skin or assembled into large power stations. Because of its modularity, it is accepted as a means to serve energy needs in dispersed and isolated communities. It can be designed to be very robust and reliable whilst at the same time it is quiet and safe. PV fits well in the existing infrastructure and it offers possibilities to make intelligent matches between electricity supply and demand.

The total amount of solar energy reaching the earth's surface represents several thousand times the world total energy consumption; the technical potential of converting solar energy directly into heat or electricity, including PV, is large: greater than 440 000 TWh/year i.e. about four times the earth's total energy consumption[1]. In Europe, fitting the total surface of south-oriented roofs with PV equipment would enable full coverage of our electricity needs. This illustrates that PV could ultimately supply a substantial part or even the majority of our future electricity needs.

Large-scale implementation of PV is a process that requires a long-term approach. Therefore, the scope of this report is 2030 and beyond. Although reliable PV technology is already available today, it needs further development, especially to reduce the cost of electricity produced. In addition, even assuming high market growth figures, it will take a substantial period of time before PV becomes a major global source of energy in absolute terms. This is not due to a lack of vitality of PV, but highlights how long it takes to change patterns in the energy sector. On the other hand, however, the economic benefits of a growing commercial PV sector are already proving a reality and have led to strong global competition.

The coming decade is considered decisive in terms of which countries or global regions will dominate the future PV sector. In view of its excellent technology and market starting position, the EU has a unique opportunity to build a large and highly innovative economic sector, while at the same time developing a key building block for a sustainable energy supply. This requires an ambitious and coherent policy on research and development (R&D), market incentives and communication, and the removal of barriers, as outlined in this proposed vision for 2030 and beyond.



---

[1] World Energy Assessment: Energy and the challenge of Sustainability, UNDP, New York, ISBN 92-1-1261-0 (Chapter 5: Energy Resources)

THE CURRENT SITUATION

The international agenda

Combating climate change is one of the most decisive challenges mankind has ever faced. The Intergovernmental Panel on Climate Change has stated that greenhouse gas (GHG) emissions need to be reduced by half, from their 1990 levels, so that they can be sufficiently absorbed by the Earth's ecosystems, to allow the concentration in the earth atmosphere to stabilize. Such stabilization is the main agreed objective of the 1992 United Nations Framework Convention on Climate Change (UNFCCC), which has been ratified by most countries of the world.

Given the need for developing countries to increase their use of energy (from levels which are, for most of them, approximately one tenth of those of industrialised countries), it is generally accepted that industrialised countries should reduce their emissions by a factor of 4, on average, if the GHG reduction targets are to be met. However, this would not lead to a return to pre-industrial CO_2 concentrations and climate conditions, but would allow stabilisation of CO_2 concentrations at a level of 450 ppmV, limit the magnitude of climate change and facilitate adaptation.

The Kyoto Protocol is only the first step in the implementation of the UNFCCC. It provides for an overall reduction of 5.2% of GHG emissions from industrialised countries between 1990 and 2008-2012. The target is 8% for the European Union.

At world level, "business as usual" energy scenarios show that consumption could grow from around 10 Gtoe to around 25 Gtoe by 2050. These scenarios also show a sharp increase in CO_2 emissions, which is in contradiction with the objective of the UNFCCC. Reducing energy demand through appropriate policies, including research, is therefore of utmost importance.

The international community also seeks to achieve the Millennium Development Goals[2], which set forth the "development agenda" for the coming years, with priorities including health, education, and poverty eradication. At the 2002 Johannesburg World Summit on Sustainable Development, energy was high on the agenda, and it was recognised that access to energy for the poor was key to the development process, as it enables an improvement of health and educational conditions, as well as income generation. The European Union launched an initiative aiming at a better access to energy to foster poverty eradication. This includes the promotion of renewable energy. Also, the development of renewable energy was considered as an important means to facilitate sustainable development, and more than 80 countries joined the Johannesburg Renewable Energy Coalition (JREC) and committed to establish quantitative renewable energy development targets. The June 2004 Bonn conference on renewable energy confirmed the International Community's commitment to the development of renewable energy sources. Other initiatives were also promoted by Member States to increase the use of renewable energy.

The European policy framework

At European level, several policy documents provide the background for the deployment of renewable energies in general and photovoltaics in particular:

- White Paper for a Community Strategy and Action Plan sets a target of 3 GW[3] installed PV capacity by 2010[4]
- Green Paper Towards a European Strategy for the Security of Energy Supply sets the target to double renewables from 6% in 1996 to 12% in 2010[5]
- Directive on Electricity Production from Renewable Energy Sources (RES-e) has the objective to increase the share of green electricity from 14 to 22% by 2010[6].

European policy goals are targeted at the following:

- Increasing the diversity of energy supply sources and security of supply for Europe
- Reducing the effects on climate change
- Contributing to the sustainable economic growth of the world's economy and developing countries
- Developing a strong European high-tech industry in the field of renewable energies and ensuring its leading role in the world arena.

The development of a strong European PV industry and implementation of PV as a source of electricity in Europe is fully aligned with these policy goals.

In order to implement the Kyoto Protocol, the European Commission has also established a Climate Change Action Programme, which encompasses a wide variety of measures, many of which have already been transformed into legislation. In addition to the Directive on Electricity

[2] http://www.undp.org/mdg/

[3] All figures given in the document referring to power (W, kW, MW, GW) are peak powers

[4] 1997 White paper for a Community Strategy and Action Plan. Energy for the future: Renewable sources of energy. COM(97)599 final 26/11/1997. Figures relate to EU 15

[5] Green paper: Towards a European strategy for the security of energy supply: COM (2000)769 final, 29/11/00

[6] Directive 2001/77/EC, 27/09/2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market (RES-e Directive)

Production from Renewables, these include the setting-up of a "cap and trade" scheme for carbon emissions from large industries, a building energy efficiency directive, fiscal harmonization for transport fuel and promotion of biofuels.

While the Directive on electricity from renewables sets national indicative targets for the contribution of electricity produced from renewable energy sources for each of the EU-15 Member States, it does not propose a harmonised Community support system for green electricity. It does however, provide for an increase to 22% of the share of electricity produced from renewable sources in the Union by 2010. The Member States set quantified national targets for consumption of electricity from renewables and provide the regulatory framework for their national support schemes to achieve their targets. The Directive also provides for a simplification of national administrative procedures for authorisation and guaranteed access to transmission and distribution systems for electricity from renewable energy sources. The Directive has now been extended to the EU-25 Member States with an overall target of 21% for the share of electricity produced from renewable sources. While this regulatory framework forms the basis for the promotion of renewable electricity, it does not, as such, provide a specific framework for the promotion of photovoltaics.

The national PV policies

The present situation of the regulatory framework for photovoltaics in Europe may be described as being very heterogeneous with substantial differences between the Member States and their time planning. While a certain level of diversity within Europe is natural, this situation could be improved in terms of transparency, consistency and efficiency. One of the worst signals to the market is a continuous change of conditions, which does not give the security needed for investors.

The situation in the EU Member States

In the European Union, research activities related to PV are supported by European and by national programmes. Most PV research programmes started in the late eighties or early nineties.

PV research activities are currently organised in two different ways:

- For most Member States, photovoltaics are included in a sub-programme of a larger (renewable) energy programme and the share of PV in renewable energy programmes is different for different Member States. In some countries (e.g. Austria, Denmark), PV represents a small part of the renewable energy research programmes, and has to compete with other renewable energy options. In others, like Sweden, Switzerland or France, PV is one of the areas that are prioritised.
- In the remaining Member States, PV research fits into more general technology development programmes. R&D actions in the field of PV are funded – like in Greece - under "horizontal" research programmes covering a broad spectrum of research priorities, such as "The programme for the promotion of industrial research", or "The Programme for Demonstration projects". This is also the case for Portugal, where these activities are funded either by the Foundation for Science and Technology or by the investment programme of the Ministry of Economy.

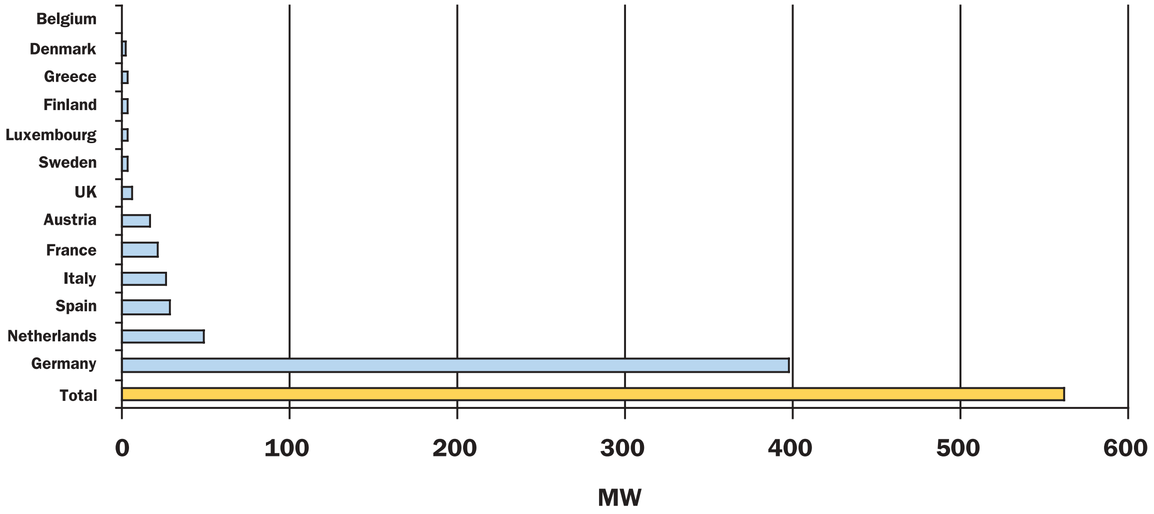
Governmental bodies are usually the main institutions involved in PV research at national level. Many national research activities are co-financed by the EU from the Framework Programme and there is little research and development coordination at European level.

Some Member States and regions have developed technology-specific feed-in tariffs to encourage uptake of PV technology, notably Germany where the "Renewable Energy Sources Act" (EEG)[7] sets an ambitious target of 1 GW for 2010. This has resulted in a tenfold market increase in four years (from 13 MW in 1999 to 130 MW

---

[7] http://solarserver.de/solarmagazin/eeg-e.html#text ; http://www.eeg-aktuell.de/

Figure 1: Total PV installed power in selected European countries by the end 2003[9].



in 2003) and a 20% price reduction. Spain has also implemented an incentive feed-in tariff by Royal Decree (RD436/2004)[8], but administrative barriers still prevent uptake. The Flanders region in Belgium plans to implement a feed-in tariff system for 2006, roughly comparable to that of Germany. All other EU Member States have very limited market deployment programmes.

It is becoming increasingly accepted that such support schemes (see Table 1) provide an effective means to achieve rapid market penetration and cost reduction for PV. Nevertheless, careful attention needs to be paid to the competitive environment and the specific conditions applied to this type of support scheme. Alternatively, some European countries have opted for a renewable energy portfolio standard[10]. However, unless technology-specific measures are taken, this will generally not form a sufficient framework for the rapid deployment of photovoltaics.

While the financial aspects of a regulatory framework are probably the most important ones in terms of their effect on market conditions for different technologies, they are not the only conditions to be met in order to create a favourable market framework. For example, unless the conditions for grid access are clearly defined, a feed-in tariff may remain fairly ineffective[11]. Moreover, while a specific regulatory framework may have positive outcomes for one or several technologies, there may also be negative side-effects from a different or macro-economic point of view. It is important to consider the arguments against certain forms of regulatory framework just as much as those in favour. There is probably no single regulatory framework which fulfils all conditions in all circumstances.

In the new Member States, photovoltaics manufacturing and installed power generation are low compared to the EU-15. The Czech Republic leads with 330 kW installed power, almost 50% of the total installed power in the ten new Member States. However there are positive signs that the situation is developing and new feed-in tariff laws are under discussion in some of the countries.

PV research and development is well established in several research centres and some companies are in early stages of development. Financial support from the EU Research programmes is increasing, following the emphasis on renewables in FP6 for new Member States.

---

[8] http://noticias.juridicas.com/base_datos/Admin/rd436-2004.html#a1

[9] EurObserver 2004

[10] Renewable electricity policies in Europe, Country fact sheets 2003; H.J. de Vries, C.J. Roos, L.W.M. Beurskens, A.L. Kooijman - van Dijk, M.A. Uyterlinde, ECN-C–03-071

[11] Subsidies versus rate based incentives for technology – economical – and market development of photovoltaics – the European experience, Th. Nordmann, 3rd PV World Conference, Osaka, Japan, 2003

Table 1: Regulatory framework for PV in EU-25 and Switzerland (2004)*

Austria	Feed-in tariff paid for 20 years with cap of 15 MW, but only for systems installed in 2003 and 2004 (cap was already reached after four weeks); 0.6 €/kWh < 20 kW, 0.47 €/kWh > 20 kW
Belgium	Feed-in tariff: 0.15 €/kWh
Cyprus	Feed-in tariff: 0.12 – 0.26 €/kWh and investment subsidies up to 55% for private investors and up to 40% for companies.
Czech Republic	Feed-in tariff: 0.2 €/kWh for one year; reduced VAT and subsidies of 30% (private: < 2 kW; legal entity investors: < 20 kW); planned Renewable Portfolio Standard (RPS).
Denmark	No specific PV programme, but settlement price for green electricity.
Estonia	Feed-in tariff: 0.07 €/kWh; RPS for electricity (11% by 2005, including large hydro); green certificates
Finland	Investment subsidy up to 40%.
France	Feed-in tariff: 0.15 €/kWh for systems < 1 MW for 20 years in continental France, 0.30 €/kWh in Overseas Department and Corsica; 5.5% VAT on investments on existing buildings, 15% tax credit for individual tax payers (40% in 2005).
Germany	Feed-in tariff for 20 years with built-in annual decrease of 5% from 2005 onward. For plants (not buildings and sound barriers), the decrease will be 6.5% from 2006 onward. The second REE injection law has been approved by the German Federal Chamber, the Bundesrat: 0.46 €/kWh minimum; on buildings and sound barriers 0.57 €/kWh (< 30 kW), 0.55 €/kWh (> 30 kW) and 0.54 €/kWh (> 100 kW), for façade integration there is an additional bonus of 0.05 €/kWh.
Greece	Feed-in tariff: 0.08 €/kWh on islands and 0.07 €/kWh on the mainland. Grants for 40-50% of total cost. Holds only for commercial applications >5 kW, no grants for domestic applications.
Hungary	Feed-in tariff: 0.073 €/kWh until 2010, soft loans; tax reduction, investment and R&D subsidies for RES (private: max 1 k€; companies: max 140 k€; annual funding: 1.2 M€).
Ireland	Alternative Energy Requirement tender scheme (no targets for PV).
Italy	Investment subsidy, feed-in law was passed in February 2004 but regulations and tariffs are not defined yet (expected for 2005).
Latvia	Feed-in tariff: double the average sales price (c 0.15 €/kWh), for 8 years, then reduc-tion to normal sales price; RPS for electricity (6% by 2010); national investment programme for RES since 2002; “soft” loans granted by the Latvian Environmental Investment Fund.
Lithuania	Feed-in tariff: 0.056€/kWh
Luxembourg	Feed-in with quota (1% of total energy consumption). For systems < 50 kW: municipalities 0.25 €/kWh and private investors: 0.45 €/kWh (after the revision of the law in January 2004); in addition investment subsidies up to 40% possible (this was also reduced for systems > 10 kW).
Malta	No specific PV programme yet, but reduced VAT 5% instead of 15%.
The Netherlands	Feed-in tariff: 0.068 €/kWh
Poland	Tax incentives: no customs duty on PV and reduced VAT (7%) for complete PV systems; soft loans (3%) for up to €650,000, max. 5 years and subsidies up to 50% of total costs. April 2004 law: tariffs for all RES-e have to be approved by the regulator; RPS for electricity (2.85% in 2004 and 7.5% in 2010)
Portugal	Feed-in tariff: 0.41 €/kWh (systems < 5 kW) and 0.224 €/kWh (> 5 kW). Investment subsidies and tax deductions.
Slovakia	No specific PV programme. Tax deduc-tion on income earned. RE exempt from income tax for 5 years; “soft” loans (granted on case-by-case basis)
Slovenia	Feed-in tariff: 0.37 €/kWh (systems < 36 kW) and 0.065 €/kWh (> 36 kW) for 10 years; soft loans; subsidies: up to 40% of costs for off-grid PV, plus 10% for SMEs, plus 10% if PV sole electricity source
Spain	New feed-in law passed in March 2004, which went into effect immediately. 0.396 €/kWh < 100 kW (previously limited to 5 kW systems); > 100 kW 0.216 €/kWh. Duration of payment 25 years, with payment on 80% of rated power output beyond that. The decree has also lifted the 50 MW cap, being now 150 MW
Sweden	No specific PV programme. Electricity certificates for wind solar, biomass, geothermal and small hydro. Energy tax exemption.
Switzerland	Net metering with feed-in tariff of min. 0.15 CHF/kWh (0.10 €/kWh); investment subsidies in some cantons; promotion of voluntary measures (solar stock exchanges, green power marketing).
United Kingdom	Investment subsidies in the framework of a PV demonstration programme. Reduced VAT.

* adapted from A. Jäger-Waldau, H. Ossenbrink, H. Scholz, H. Bloem and L. Werring, 19th European Photovoltaic Solar Energy Conference and Exhibition, Paris, June 2004; S.Pietruszko (PV-NAS-NET coordinator), private communication

The situation in the USA

The U.S. Department of Energy (DOE) leads federal PV activities under the “National Photovoltaics Program”. This programme, carried out by the National Center for Photovoltaics, the National Renewable Energy Laboratory (NREL) and Sandia, follows a well-established national paradigm – the forming of partnerships among national laboratories, industry and universities. It aims to support the U.S. PV industry in improving the cost-effectiveness, performance, and reliability of its products. Industry generally provides support for basic and applied research and development.

On the other hand, there is no real market deployment policy at federal level. The ongoing deregulation process of power utilities has resulted in several programmes being proposed and legislated at State level that affect photovoltaics. These include “Green pricing”, set-asides for photovoltaics, net metering, interconnection requirements, etc. Initiatives related to the promotion of photovoltaics are individually adopted by each of the 50 states. The State programmes are too diverse to summarise in this report.

The situation in Japan

The Japanese government has, over the last ten years, implemented a coherent long-term PV policy including R&D, demonstration tests, market deployment and promotion. This continuity makes the implementation of PV, both in manufacturing and into the market, very effective. A new law encourages the introduction of 5 GW capacity of PV systems by 2010. Research and development, to reduce costs of PV systems and to promote innovative next generation technology is also under way. Standardisation issues are being addressed, and PV is being actively promoted through the Residential PV System Dissemination Programme. In addition, the Government has implemented support programmes for the introduction of new energy directed at local governments and private entrepreneurs.

The Japanese “PV2030” roadmap[12], outlines possible development routes of PV, leading to 50-200 GW of PV in 2030 (baseline case 100 GW). The technical potential is estimated to be 8 000 GW. Research and development is aimed at reaching break-even with household electricity prices in 2010 (0.17 €/kWh)[13], business electricity prices in 2020 (0.10 €/kWh), and industry prices in 2030 (0.05 €/kWh). Japan has a net metering (~0.2 €/kWh) scheme complemented by a relatively low subsidy (only 12%). Implementation is successful, and at the end of 2003 some 180 000 systems were installed with a total capacity of 700 MW.

Comparison between Japan, USA and Europe

Figures from the IEA on public expenditure for PV research show that Japan invests significantly more public funds in support of PV development than the EU or the US, as shown in Table 2. These figures do not include the cost of feed-in support schemes which are substantial in Japan (PV tariff = 0.3 €/kWh) and in Germany (0.5 €/kWh before 2004). In Germany, the cost of R&D programmes was $22.2 million in 2002, whereas the feed-in support scheme cost $55.9 million (note that these costs are covered by a small increase of consumer tariffs).

Furthermore, 90% of European public expenses come from national PV RTD programmes (38% of the European financial effort is made in Germany), and there is no formal coordination between these programmes. In comparison, the US and Japanese national programmes are well coordinated.

The situation in China

There was 50 MW installed capacity of PV at the end of 2003 in China, of which 10 MW was installed in 2003. However, the Chinese industry is increasingly visible at international PV fairs and forums. PV seems to be part of the Government’s drive toward a strong

Table 2: Public Expenditure on PV research and market deployment in 2002[14]

(million US $)	R&D	Demonstration	Market deployment	Total
Japan	59	36	185	280
Europe	58	11	62	131
USA	35	0	80	115
ROW	20	9	13	42
Total	**172**	**56**	**340**	**568**

---

[12] METI (Ministry of Economy, Trade and Industry) report June 2004

[13] Assuming 1 € = 135 yen

[14] IEA PVPS, annual reports 2002 & 2003, member country contributions

development of RES; the objective announced at the recent World Renewable Energy Conference held in Bonn in June 2004 being a 10% share for RES of electricity generation by 2010.

The situation in the developing world

Due to the lack of information regarding the PV markets in the developing world, it is difficult to describe the current situation of the PV industry in these regions. However, it is estimated that 156 MW were installed in the Rest of the World (ROW) in 2003.

The current PV status in the developing world is characterised by a rural isolated market for stand alone systems, financed by development banks, national cooperation agencies, and all multilateral organisations like the World Bank, Asian Development Bank, Inter-American Development Bank, United Nations, European Union, among others, through development and cooperation projects. This situation has created a market that is impossible to predict and too dependent on rural electrification PV projects. However, an important portion of the funds is being directed towards the removal of market barriers for the dissemination of renewable energy, thus promoting the creation of rural PV markets.

Today, there is no doubt that institutions like the United Nations and the World Bank are developing a new approach and are working together with national governments on how to fight poverty and increase quality of life. Through initiatives like the Millennium Development Goals and Global Compact, among others, the international community is changing the face of co-operation and development, and photovoltaic technology will be an important part of this process. India is a great example; it has been able to promote a rural PV market, while developing its own industry.

PV in the context of renewable energy sources

In 2001 the share of renewables in the world was 13.5% of the total primary energy supply and 19% of the total electricity consumption[15] (see Table 3). Hydroelectricity represents the main renewable source of electricity covering 16% of the world electricity demand. The contribution of other renewable sources depends upon national energy policies and local conditions. In some countries, specific renewable energy sources already contribute significantly to the energy supply, e.g. wind energy in Denmark and geothermal energy in Iceland and the Philippines. The rapidly rising supply of electrical energy comes from a range of renewable energy sources: modern biomass technology, wind energy, solar-thermal energy and PV. Some of these renewable sources may contribute to the world energy consumption also in the form of heat or mechanical energy.

Current electricity generation costs from renewables range from 0.02 to 0.65 €/kWh, as summarised in Table 3. The different costs of electricity for each renewable energy source are highly dependent upon local conditions, on the amount of wind or solar radiation available, or the temperature of a geothermal field for example. PV electricity costs of 0.25-0.65 €/kWh are high compared to the current wholesale price of conventional electricity, 0.02-0.035 €/kWh. Even if the added costs to cover the capture and sequestration of CO_2 bring the price of conventional electricity to a total of 0.04-0.055 €/kWh, it still remains competitive compared to PV used as a central power source. Though conventional electricity costs are predicted to rise to 0.05-0.06 €/kWh by 2020, there is a need to bring PV costs down by at least a factor of 5 to reach full deployment.

All renewable sources have some limitations to their use, be it location, availability of suitable climatic conditions, etc. However, renewables can be effectively combined to provide a consistent and reliable supply. PV as a peak load electricity source is to a large extent compatible with base load sources such as geothermal and marine energy and also with storable sources such as bio-energy and pumped hydro-storage. As with conventional energy sources, the diversity of renewable energy sources is important to ensure security of supply.

One of the main characteristics of PV, and an advantage with respect to other renewable energies, is that it can produce electricity at the point of utilisation. In addition, the PV resource is geographically spread evenly, meaning that it can be applied almost anywhere. Last but not least, due to the very early stage of development of photovoltaic technology, the electricity generation cost of PV can be expected to decrease far below current prices in the future, enabling competitive generation on a very large scale.

Current status and technological potential of PV technology

The foundation for modern PV technology was laid in the early 1950s, when researchers at Bell Telephone Laboratories discovered and developed crystalline silicon solar cells. In 1958, similar cells were used successfully in space. Although at the same time attempts were made to commercialize silicon solar cells on a larger scale, it took until the 1980s before markets were sufficiently developed to warrant production at any significant scale. From then on, laboratory and commercial PV technology development has shown steady progress. This has led to a portfolio of available PV technology options at different

---

[15] IEA "Key World Energy Statistics", 2003

Table 3: Electricity production from renewable sources, technical potential of RES and electricity generation costs

	World electricity production 2003 (TWh)	World energy technical potential heat and electricity (x 1 000 TWh/year[16])	Electricity generation costs 2003 (€cents/kWh)
Hydroelectricity	2 631	14	2 - 8
Bio-energy	175	>77	5 - 6
Wind energy	75	178	4 - 12
Geothermal power	50	1400	2 - 10
Marine energy	0.8	32	[8 - 15]*
Solar thermal energy	0.5	>440	12 - 18
PV	2,5		25 - 65
Total renewable electricity production	2 969	>2 100	
Total world consumption	Electricity ~ 16,700 Total primary energy ~ 120,000		

* estimated costs

levels of maturity, and experience that can be expressed by a robust learning curve (price reduction vs. cumulative production of commercial PV).

A PV system consists of a module (array of *cells* generating the electricity) and a balance-of-system (BOS) including (if applicable) the cabling, battery, charge controller, dc/ac inverter and other components and support. It is noted that the BOS-costs also include labour to build a turn-key system. Most systems are so-called "flat-plate", i.e. collecting solar energy directly on the module. Flat-plate systems are usually static with a fixed orientation, but sun tracking may also be used. A distinctly different type of system uses an optical system in combination with sun tracking to concentrate sunlight onto a small-area high-efficiency solar cell.

Commercial PV modules

PV modules may be divided into two broad categories:

- wafer based crystalline silicon (c-Si)
- thin films, which include thin-film silicon, copper-indium/gallium-selenide/sulphide (CIGS), amorphous silicon (a-Si) and cadmium telluride (CdTe).

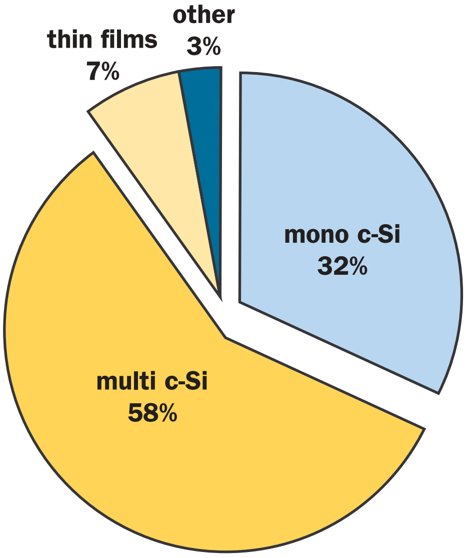
Wafer-based crystalline silicon is the dominant technology (Figure 2) because it is widely available, it has proven reliability and it is well understood as it is founded on the knowledge and technology originally developed for the electronics industry. Crystalline Silicon modules are typically produced by growing ingots of silicon (in a manner similar to that used for the electronics industry), slicing the ingot to make wafers, processing these wafers into solar cells, electrically interconnecting the cells, and encapsulating the strings of cells to form a module. Since high-quality feedstock is required and the overall silicon utilisation is still relatively low (a large fraction of the silicon is lost during processing), material costs are high compared to thin film modules. In addition, manufacturing is often not yet optimally automated (see the Strategic Research Agenda). Finally, current silicon feedstock production is energy intensive. Together with the low silicon utilisation, this leads to a module energy pay-back time of several years, although much shorter than the module lifetime.

Thin-film modules are made by coating and patterning entire sheets of substrate, generally glass or stainless steel, with micron-thin layers of conducting and semiconductor materials, followed by encapsulation. This leads to a process that can be highly efficient in materials utilisation, has relatively low labour requirements, and uses comparatively little energy in the total manufacturing process.

---

[16] World Energy Assessment: Energy and the challenge of Sustainability, UNDP, New York, ISBN 92-1-1261-0 (Chapter 5: Energy Resources)

Figure 2: Distribution of cell production by technology[17]



The total area stable efficiencies of these modules are in the range of 5 to 15%. In principle, these efficiencies are high enough to enable large-scale use. Nevertheless, efficiency improvement is crucial in order to reduce module manufacturing costs per watt-peak which will in turn lead to lower system costs (because area-related BOS-costs are reduced) and allows for efficient use of scarce or expensive space, which may become an issue in densely populated regions.

Efficiencies of current technologies could be increased to 15-20% or slightly higher. Further increases are possible but would require a fundamentally different approach as outlined in the Strategic Research Agenda. It is expected that the range of commercial module efficiencies will be 10-30% or higher, by 2030, while at the same time fulfilling the requirements of cost reduction. These figures may refer to very different technologies and applications, such as polymer-based module “foils” or super-high-efficiency sun-tracking concentrator systems.

Even if crystalline silicon (c-Si) dominates the market, with 95% market share at present, due to reliability and performance, there is still potential for further improvement in terms of manufacturing costs and efficiency. The learning curve of PV modules (Figure 3) has been fully determined by c-Si in the past and is expected to continue to be so for the next 10-15 years.

The market share of thin films has remained at very modest levels over the past decades and reduced from 15% in 1995 to 5% today. Thin films have the important potential to extend the PV learning curve beyond the point that may be reached by crystalline silicon technology, CIGS, as an emerging technology, could compete with c-Si but further development and scaling up of manufacturing is necessary. Thin-film technologies further allow for specific applications (flexible modules, semi-transparent modules, etc.). To realise the potential of thin films, the PV industry and research sectors have to work together closely to solve both fundamental and technological problems. After 2010, the share of thin-film technologies is expected to increase.

The current investment necessary for production equipment for wafer based crystalline silicon is approximately 0.5 €/W of annual production capacity, whereas additional investments for building, infrastructure, electricity and gas supply, waste management and recycling, etc. bring the total investment requirement to 1.5 €/W. This represents approximately 75 million euros for a 50 MW manufacturing plant.

To date, no actual manufacturing plant has proven the cost benefit potential of thin films in practice. There is still a lack of maturity of processes and equipment, and material and energy costs still have to be optimised. The major cost element for thin films is the capital for equipment and materials, and the cost of the materials will be the key to achieving low overall module costs in the long term.

The price of standard PV modules is currently approximately 3 €/W. This could be reduced to 2 €/W by 2010, 1 €/watt-peak in 2020 and 0.5 €/W in 2030. After 2030 a further price reduction is expected. These figures are supported by the historic learning curve for PV modules, which shows a 20% price reduction for every doubling of the accumulated sales (see Figure 3).

Cost reduction can only be achieved by continued market growth in combination with focused research efforts, and with cross-fertilisation and spin-offs from other high-tech industry sectors like flat panel displays, micro-electronics, nanotechnology, the automotive industry and the space sector. The most important areas for research into crystalline silicon technology and thin film technologies are explored in the strategic research agenda section (see later).

---

[17] P.D. Maycock, PV Market update, 2003

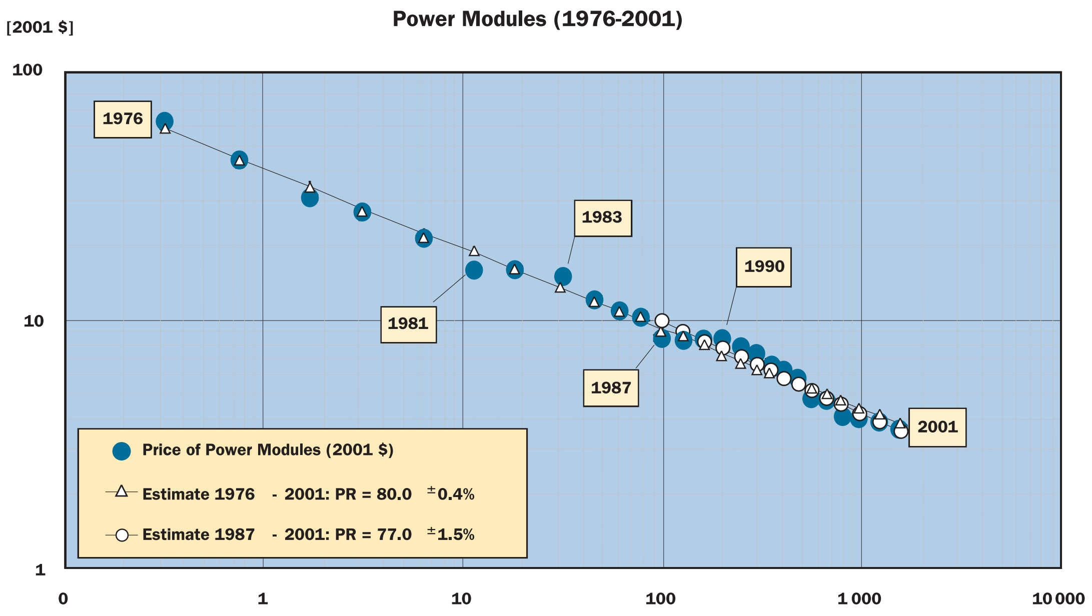


Figure 3: Learning curve – PV module prices (per Watt) against cumulative shipment (in MW)[18]

PV concentrator technologies

In addition to crystalline silicon and thin film flat-plate modules, concentrator technologies have a share in commercial PV. Very high efficiency small area solar cells (which may be expensive per unit area) in combination with large area optical concentrators are an important alternative route to low generation costs. Concentrator systems are based on the substitution of expensive solar cells elements by cheap optical elements. Higher total system costs (optics, tracking, cooling, etc.) are compensated for by higher efficiency.

Emerging and new technologies

A variety of other PV technologies and conversion concepts are the subject of research in and outside Europe. They are all aimed at low cost, high efficiency or a combination of the two. New technologies are at various stages of development: from proof-of-principle to pilot production. Most still require fundamental research to show the basic potential for commercial use.

A key factor in reducing of the cost of modules is connected with the manufacturing processes used. In this context there is considerable interest in replacing single crystalline and polycrystalline semiconductor layers by nanostructured layers, which may be deposited very cheaply, using experience from other sectors.

New technologies can be categorised as:

- Options primarily aimed at very low cost (while optimising efficiency)
  - sensitised oxide cells
  - organic solar cells
  - other nanostructured materials.
- Options primarily aimed at very high efficiency (while optimising cost)
  - multi-junction cells for use in concentrators
  - novel conversion concepts.

Some technologies, such as sensitized oxide and multi-junction cells, are more mature and are gradually moving out of the laboratory phase while others are still in the early stages of development. Organic (or “plastic”) PV is often considered a high-risk, high-potential option. Working devices have been demonstrated, but efficiencies are still low and sufficient stability has yet to be proven. Finally, novel conversion concepts will be based on a variety of principles, and can be considered to be at the fundamental research stage.

---

[18] Strategies Unlimited, 2003

For technologies that are not yet in production or are in pilot-production, it is very difficult to estimate future manufacturing costs; for laboratory concepts this is even impossible. Therefore the present focus for research is on efficiency, stability and lifetime.

The PV industry

After a slow start, the worldwide PV market has been growing at an average annual rate of approximately 35% (from 150 to 750 MW) over the past 5 years. This success has been generated by a combination of market stimulation and intensive research and development in Japan, the USA and Europe, over the last 10 years. Prices have been reduced by a factor of 3 since 1990. Cumulative worldwide installations are estimated to 2.2 GW by the end of 2003, with Europe standing at 560 MW, as shown in Figure 1.

The European PV production in 2003 reached 200 MW (Figure 4) which represents approximately 26% of the worldwide PV production (750 MW). Japanese manufacturers have significantly increased their market share, in terms of production, 1995 to 2002, from 21% to 49% and this looks set to grow even higher.

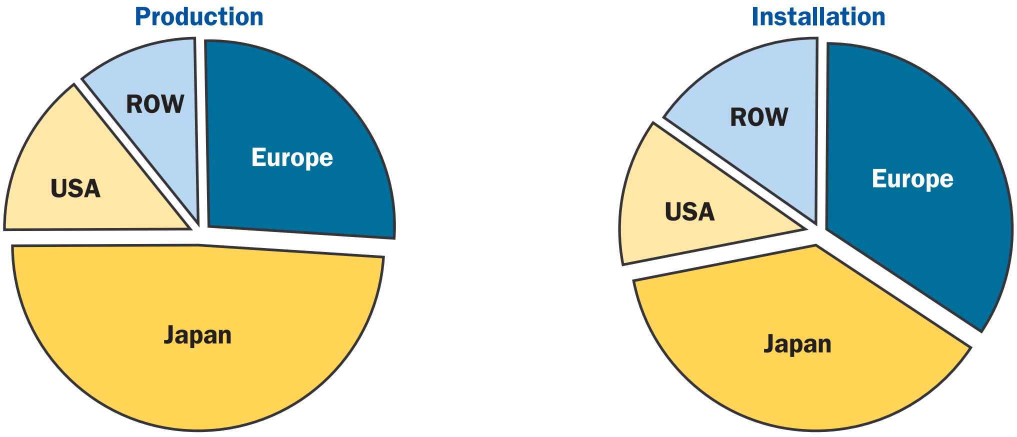
The installation of PV in Europe in 2003 represents 34% of the world PV market, against 38% in Japan. With 49% of the world production far in excess of their domestic market, Japan is a net exporter of PV. The market has grown in Europe at a consistent rate compared with other large markets (Japan and USA). In contrast, the intensity of technological development efforts and the increase in production capacity are much lower in Europe than in Japan.

Systems and applications

The environmental profile of PV systems is determined primarily by the energy content, the use of scarce or hazardous materials, and the possibilities for recycling. A key parameter related to the use of PV as a renewable source of energy is the so-called energy pay-back time, which is now typically 2-4 years, or ~10% of the operational lifetime. These numbers may still be improved substantially, namely to less than 1 year and less than 3%, respectively. The CO_2 emission related to the energy content is dependent on the source of this energy and may be reduced to zero if the solar or another renewable source is used. In today's systems the environmental profile is determined mainly by the modules, but there are potential gains to be achieved from careful specification of electricity conduction materials and power electronics.

A PV system can either be connected to the grid (with a power range of 100 watts to several megawatts) or be used as a stand-alone system (ranging from a few milliwatts to several kilowatts) with or without storage support. Grid-connected systems and stand-alone systems are very different, but equally possible for large-scale use. Grid-connected generators have the biggest potential to make a substantial contribution, in quantitative terms, to the sustainable energy supply in Europe. Stand-alone systems, on the other hand, could make an important difference to many people in developing countries. Even if the total

Figure 4: PV market regional shares in 2003[19]



---

[19] PVNET European Roadmap for R&D, 2004, EUR 21087 EN

[20] If all individuals without access to a grid (some 1.7 billion) used one solar module of 50 watt-peak, the electricity produced would equal roughly 500 petajoule, or 0.1% of the global (primary) energy consumption

amount of electricity produced by stand-alone systems were to be modest[20], such systems would play a key role in providing essential services such as lighting, cooling, telecommunication, water pumping and sanitation, etc.

Grid-connected systems

Decentralised generators: Due to the characteristics (modular, quiet, no moving parts, little maintenance, no emissions, etc.) PV systems are very well suited for integration in buildings and infrastructure such as objects like sound barriers. Such decentralised applications make PV the renewable energy source of choice for densely populated regions and countries. The technical potential of integrated PV is large; by making full use of the available area (roofs, façades, etc.) EU countries could generate an amount of electricity comparable to the total consumption. Even if this comparison is somewhat unrealistic, due to the mismatch between generation and demand, it underlines the importance of decentralised generation.

Central power plants: On dedicated areas, large “ground based” power plants can be implemented. Today’s systems range from a few hundred kilowatt-peak to several megawatt-peak, but very large scale systems in the power range up to a gigawatt-peak are being studied or even under preparation. Such systems may be based on fixed (or sun tracking) flat plate modules or on sun tracking concentrator modules. The electricity produced can be fed into the grid or used e.g. for future hydrogen production.

Grid-connected systems in the EU can generate 0.6-1.5 kWh/W.year, depending on the location which is equivalent to 80-200 kWh/m^2.yr for today’s most efficient systems. This implies that a system of 20-30 m^2 would be able to generate electricity equal to a household’s demand on a yearly basis, although intermittency of supply with demand needs will need to be addressed. Future generations of systems may yield 160 to 400 kWh/m^2.year or even more.

Turn-key system prices in 2004 are typically 5 €/W (excl. VAT), even if dedicated designs and some applications require higher material, engineering or installation costs. Depending on assumptions concerning economic lifetime, operation and maintenance (O&M) costs, interest rates, electricity generation per watt-peak system power, etc., the turn-key price can be translated to electricity generation costs. For the best systems available and well-chosen sites the figure of 5 €/W roughly corresponds to 0.25-0.65 €/kWh, depending on location (solar irradiation level) in the EU. Detailed analyses of the potential for price reduction[21]-[22] have shown that system prices may be reduced to 3.5 €/W by 2010, 2 €/W by 2020 and less than 1 €/W in the long term (i.e. 2030 and beyond). Studies are being carried out to determine the lowest achievable price. This knowledge is important for the competitiveness of PV in future bulk electricity markets. Since the BOS accounts for roughly 40% of the turn-key system cost, drastic cost reductions are required in this area along with cost reduction of modules. Two topics require particular attention: inverters and mounting/building integration of modules.

The performance of today’s grid connected systems is already quite good in absolute terms; energy losses on a system level have been effectively reduced to approximately 10-15%[23], (design) lifetime of components has been increased to 15 years or more and system availability is generally between 95 and 100%. The potential for further improvement lies in an increased overall system lifetime of 25 to 40 years (at reduced cost) and a slight further reduction of losses. The specific system energy yield (electricity delivered to the grid normalized to installed module peak power) is in the range of 0.6-1.5 kWh/W per year for fixed modules, again dependent on location. By applying sun tracking the yield is enhanced by 25% or more, albeit at increased BOS and O&M cost.

Stand-alone systems

Stand-alone PV systems are often the preferred option for high-value applications such as rural access to electricity. Although many well-designed, well-engineered and well-maintained systems operate according to expectations most of the time, and significant improvements in system reliability and availability are crucial if PV systems are to become a key technology for off-grid applications. Robustness, ease of repair, availability of replacement parts and low everyday maintenance requirements are essential, as is the need for a thorough understanding of the interaction between users and system hardware.

Stand-alone PV systems are already able to compete with alternative sources of electricity such as diesel generators; however, a further decrease of costs will facilitate their use on a much larger scale. Because of the wide range of stand-alone system types, prices (i.e., per W) differ considerably. Compared to grid-connected specific systems, costs are generally higher because of a larger BOS-share, but this comparison does not take into account the different operating environments. A reduction of the *life cycle cost* (initial investments, replacement costs, O&M costs) is also essential. In particular for systems with battery storage, the environmental profile is still a matter of concern.

---

[21] EPIA roadmap 2004

[22] PVNET European Roadmap for R&D, 2004, EUR 21087 EN

[23] Related to module mismatch, cabling, dc/ac conversion, etc. and not to module behaviour itself

Applications

PV systems are utilised in several forms:

Consumer applications: watches, calculators, garden lights, alarm devices, etc.

Industrial applications: telecommunication relays, cathodic protection, tele-measurements, and all applications for which the electrical consumption is small compared to grid connection like parking meters even in towns, or emergency phones along highways

Remote dwellings in industrialised countries: thousands of dwellings in Europe are too far from the grid to be connected, but they can benefit from PV generated electricity for lighting, television, refrigeration, etc.

Decentralised rural electrification (DRE) in developing countries: concerns about 1.7 billion people in the world according to official IEA figures. DRE aims to meet:

- *Basic needs:* potable water, water for livestock, refrigeration and lighting for a dispensary
- *Improved quality of life:* residential lighting, telephone service, radio and television and community lighting (street lighting, schools, meeting halls, etc.)
- *Small-scale motorisation for development:* pumping for farming irrigation, vegetable gardening, storage, motorisation for mills, presses, small craft industries, etc.

The capability of PV to be utilised in certain applications under current economic and technical conditions depends on the geographical location and the climatic zones, as well as cost. PV generators are generally a good solution for basic needs in rural applications to improve living standards. To solve the problems associated with intermittency and dispersion, hybrid solutions can be implemented combining the use of the full range of renewables, solar, hydropower, wind in coastal areas, and biomass. Lower cost and increased performance PV will ensure that uptake in all markets is increased in the future.

A VISION FOR PHOTOVOLTAICS

The main driving forces that require a dramatic change in our energy consumption patterns include the depletion of oil and gas resources, climate change considerations, the need to ensure security of supply, the lack of access to commercial energy of one-third of the world's population and the expected economic growth of emerging countries. The developed world represents only 20% of the total population but it consumes 80% of the world's resources whilst at the same time producing a large proportion of environmental waste and air pollution. On the other hand, the developing world is struggling with the difficulties of economic development, and the fight against poverty.

The transition to a sustainable global energy system is one of the biggest challenges mankind has ever faced.

This transition will take 30 to 50 years or more, even though the necessity for change is urgent, due to the negative ecological consequences the world is experiencing right now. This process involves huge financial investment and a strong and continued political commitment.

In the context of this transition, PV is a key technology. The current relatively early stage of development indicates a large potential for steady and high rate of growth up to and beyond 2030. It is envisaged that by 2030, PV will be established as a viable electricity supplier, and that the market will continue to grow thereafter at full speed. Forecasts should therefore only be seen as intermediate ones, and are by nature subject to significant uncertainties.

Technological development

Impressive progress in PV technology has been made over the past decades. This is evident by the price reduction (roughly a factor of 5 over the past 20 years), by the efficiency increase of commercial and laboratory technologies (typically by 50% over the same period), by the ample technology options portfolio and by the strongly improved system reliability and yield.

The period until 2030 will show rapid further maturing of commercial technologies, leading to flat plate module efficiencies in the 10-25% range (35% for concentrators) and generation costs down to 0.05-0.12 €/kWh. Beyond 2030 a further reduction of generation cost is expected. All technologies, crystalline silicon, thin film and new concepts may be significantly present on the market.

In 2030, PV systems will have a standard technical lifetime of up to 40 years. Yearly operation and maintenance will be 0.5-1% of the investment costs. PV modules and systems will be exclusively based on abundant and non-toxic materials, or fully closed cycles and the energy pay-back time of systems will be less than one year.

After 2030, module efficiencies will increase further as a result of successful implementation of the new concepts. Ultimately, PV module will have an energy conversion performance in the 30-50% range, allowing very efficient use of available area. One square meter of the highest efficiency PV modules installed in sunny regions will then yield 1 000 kWh of electricity per year.

By 2030, PV system elements will have developed into versatile building components, facilitating standardised and specific uses on a large scale. Almost all new buildings will be fitted with PV arrays, and many will be net producers of electricity.

Very large-scale implementation of PV will require combination with back-up from other renewable energy sources and the development of advanced balancing and storage technologies.

In the even longer term, other options will exist, like large desert-installed PV plants supplying power to distant consumers via a worldwide electricity grid. Also, hydrogen production from PV electricity (combined with subsequent electricity generation by fuel cells) may become an option if conversion yields can be improved. The development of new lighting technologies like LEDs, flat panel displays, etc, which can be supplied with direct current at low voltage, may allow converters to be eliminated and further reduce the installation costs of PV systems.

Socio-economic aspects

By 2030, PV will have developed into a large economic sector, both worldwide and in Europe. There will be a strong European PV industry with significant exports. The number of jobs created in the EU will be between 200 000 and 400 000 (based on a European yearly production of 20-40 GW), many of them linked to the installation and building sectors. These jobs will therefore be spread geographically and between SME's and large companies.

Depending on the application, a wide range of commercial solar cell technologies will be available each with its own features. There will be a range of products with different efficiencies for use in particular application areas. PV will be available as multi-purpose solar modules (flat-plate or concentration), a variety of building products and as integrated products (OEM-components with solar power[24]). A wide range of appliances making direct use of PV power (e.g. light emitting diodes) will also be common on the market.

---

[24] Original Equipment Manufacturer (solar cells integrated in complete end products, such as phones, notebooks, body warmers, etc.)

Grid-connected PV will cross the first major hurdle, namely competitiveness with retail electricity, in large parts of Europe, within ten years. Also, the use of PV equipment as building components will facilitate market penetration of roof-top systems and strongly influence new building concepts and standards. By 2030, PV generation costs will be sufficiently low to enable compete within most parts of the electricity market, all the more if fossil fuel prices continue to grow as expected and the environmental impact of PV is valued.

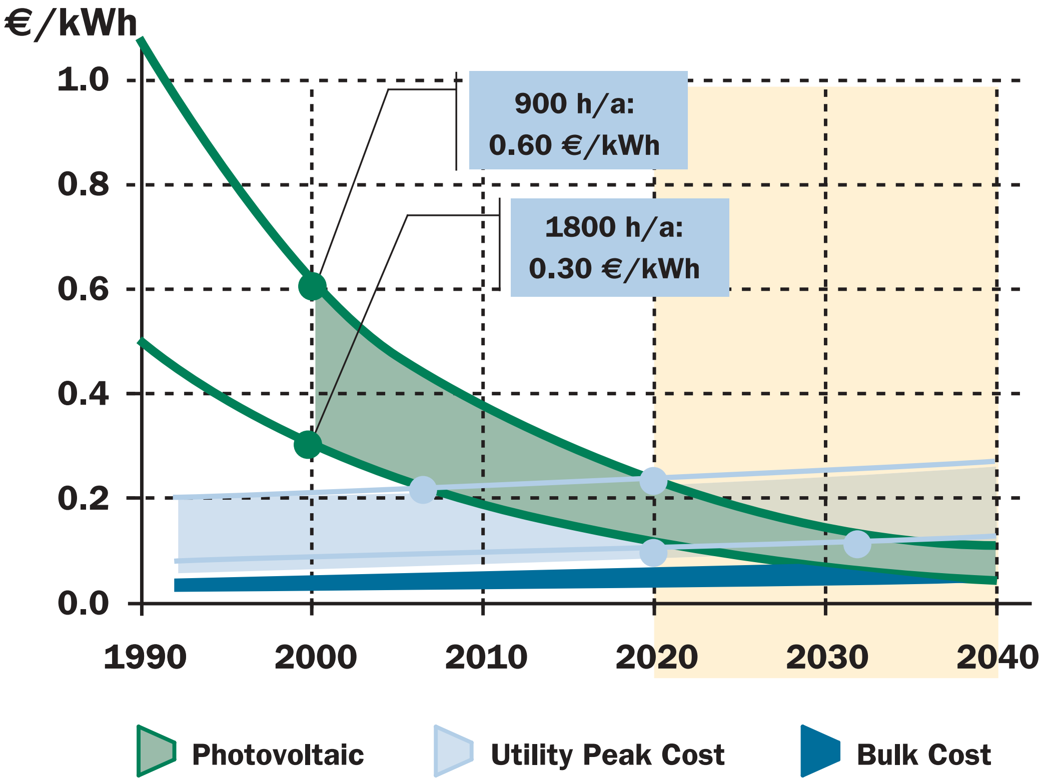
PV generation costs do not typically have a single reference level, as PV electricity can be fed into the grid at different levels or PV can be used in stand-alone systems. For grid-connected roof-top systems, the likely comparison is with end consumer tariffs including taxes, and for large PV power plants with the wholesale price of electricity (taking into account a "green" premium). For stand-alone systems, the comparison is more likely to be made with diesel generators or grid extensions. In such cases PV often is not only cleaner and more reliable, but also a cheaper option, in spite of relatively high generation costs. By 2030, it will therefore become common practice to compare the costs and quality of the *service provided* rather than the costs of the fuel or electricity.

The generation costs of PV electricity from grid-connected systems are currently in the range of 0.25-0.65 €/kWh in Europe, depending on local solar irradiation. By 2010-2015 these will have been halved, while in 2030 generation costs will be in the 0.05-0.12 €/kWh range. After 2030, the costs will decrease further aided by breakthrough technologies (Fig. 5).

The role of PV in the 2030 energy picture

In 2030, traditional energy sources will still be the major provider of energy, but the use of renewable technologies will be ever increasing. There will have been a shift from

Figure 5: Generation costs of PV electricity[25]



---

[25] EPIA: Towards an Effective Industrial Policy for PV (RWE Schott Solar)

highly centralised electricity generation to a more diversified system in which renewables play an important role. PV, wind energy, biomass, solar energy, hydropower, geothermal energy will be implemented in a complementary form to match supply needs and geographical location. In particular, PV is now seen as the preferred option to supply power at sun-induced peak periods due to its competitive cost.

The EU target for PV of 3 GW installed (approximately 3-4 TWh electricity production) in 2010, can be achieved. **With ambitious, though realistic, growth figures, the installed capacity may increase to around 200 GW (200 TWh) in the EU, and 1 000 GW (1 000 TWh) worldwide in 2030, representing 4% of world electricity production.**

These estimates are consistent with the Japanese Government's objective of 50-200 GW. They are still far below the estimated technical potential, and therefore, it is expected that PV could grow much larger in the decades beyond 2030.

PV will have become a well-known feature in our cities as well as in developing countries. The **large-scale dissemination of PV for rural use in developing countries will have provided access to electricity to more than 100 million families by 2030, thus positively affecting the lives of half a billion people (out of the 1.7 billion people who do not have such an access today).**

By 2030, the price of electricity will take full account of the environmental impact of generation, environmental impact information will be commonly available to facilitate informed customer choice and market demand for energy technologies with low environmental impacts will be strong. EU development policies and initiatives will have played a major role in achieving such a result, both within the Union and in the developing world. PV will have become a standard and well accepted option for diverse demands and applications and, together with other renewable energy sources, will be a **robust and safe supplier of energy**, supporting the grid or in stand- alone mode where or when required.

HOW TO REACH THE VISION

The previous chapters have described the various aspects – both technical and non-technical – of the present situation of photovoltaic technology, applications and markets as well as the relevant market and policy frameworks. The past 20 years of continued efforts in research, technology and manufacturing have developed photovoltaics into a rapidly growing, increasingly global industry. PV costs are falling constantly and public funding is delivering results.

Based on the long-term technical potential, at least 20% of Europe's electricity could be supplied by photovoltaics in 2050. Section 2 of this report outlines a vision of the technology, bearing in mind that development will continue beyond this date, as the full long-term potential will not yet have been tapped and a continued substantial growth can be expected. According to this vision, by 2030, large-scale industrial deployment of photovoltaics will have occurred and will offer a range of competitive energy services, thereby increasingly contributing to the electricity supply portfolio. In this context, PV will provide an important contribution to the sustainable supply of energy.

It should be noted that although the present developments are very encouraging, they are partially scattered: sometimes technology-driven and sometimes policy-driven. In order to achieve the vision, activities need to be shaped into a coherent, long-term, market-orientated strategy that includes targeted transitional actions. Given the potential of photovoltaics, ongoing activities can be strengthened by adopting such a strategy thereby enabling accelerated cost reduction, build-up of new competitive solutions and a strong industrial base. The key elements of such a strategy are:

- The need for a concerted effort, with continuity and full support of all stakeholders
- A comprehensive and structured approach
- Additional focus on critical technological issues
- Proportional accompanying measures.

Specific issues

To achieve the PV vision, the following specific issues should be addressed:

Increasing RTD efforts

While a considerable amount of research funds are presently directed towards the development of cost-effective PV components and systems, the level of effort needs to be increased to be in balance with the present market growth and the potential of the technology. In order to account for the long-term and strategic nature of these research expenditures, dedicated research and development programmes should be designed. Particular action is required in countries where national research efforts for PV are scarce.

Alignment of strategies and goals

It is crucial to position PV adequately over time with respect to its future contribution to energy supply and environmental and social benefits. The strategies and goals should clearly be formulated and separated into the short term (until 2010), the medium term (until 2020) and the long term (beyond 2020).

Continuity and long-term action

Given the timescales needed to realise the full potential of PV, continuity of action is essential. Technology development and falling costs have been a reality, and with support, this trend can be expected to continue, thereby enabling progressive developments of new competitive markets. Together with the liberalisation in the energy sector, this will provide new business opportunities.

Addressing the barriers

Besides the evident issue of high cost, several other barriers exist which hinder the large scale deployment of PV. These include technical issues, manufacturing issues, the structure of the electricity sector, standardisation, financing, education and training of installers and market awareness/public acceptance. The different barriers need to be systematically clarified and addressed, with the involvement of all stakeholders, including those outside the PV community.

Improving technology transfer

One of Europe's weaknesses, not specific to PV, is the difficulty of rapid transfer of technology from research to application. Over the past decade, various attempts have been made to improve the structural, institutional and financial approach favouring technology transfer and many positive results have been achieved, supporting "spirit of entrepreneurship, risk-taking attitudes and focus on success".

Nevertheless, cooperation between science and industry can still be improved in favour of a rapid technology transfer. Technology transfer is seen to benefit strongly from close cooperation between professionals from different environments.

Emphasising manufacturing issues

When it comes to the competitiveness of the PV industry, it is not sufficient to have excellent or even record results in the research laboratory. The technological solutions developed need to be compatible with industrial processing and up-scaling. In application-oriented research, these aspects should be addressed at an earlier stage in full cooperation with industry. Moreover, manufacturing-related issues need to be better addressed in technology development programmes (in the US for example, the programme PVMAT[26] was seen as the single most important support scheme by industry).

Enabling critical mass

European PV activities, both in academia and industry, are characterised by a large range of projects, research groups and companies, some of which are small. While this situation has grown naturally and favours healthy competition as well as a broad set of different technology options, it can hamper the formation of critical mass to penetrate the market successfully. By clustering different activities more effectively, overlap can be reduced in favour of complementary strengths. The European Research Area provides the adequate background for such developments.

Joining forces and competencies

The PV sector can benefit from stronger exchange and cooperation with other sectors of research (e.g. materials, chemistry, and nanotechnology), industry (e.g. electronics, building industry, equipment manufacturers) and the energy sector (e.g. other renewable energy technologies, decentralised generation, grid design, electricity storage). A proactive dialogue can result in new synergies where different competences allow promising new partnerships. By combining the use of PV with other energy technologies more intensively (e.g. in the building sector or in hybrid systems), PV can benefit and resolve some of its inherent weaknesses.

Building sustainable markets

The global market for PV has been growing rapidly over the past years. However, the market can be vulnerable due to policy changes which create insecurities for investment. Even if market support schemes are transitional measures, it is important to develop "sustainable" support schemes which favour private investment in the domestic and export markets.

Natural markets for PV systems exist in developing economies. Applications can offer a low-cost option to cover basic needs, but non-technical barriers exist such as system design, difficulties with financing, inadequate infrastructure, lack of maintenance availability and skills, quality and education.

Involving stakeholders and decision makers

PV is an energy technology which elicits diverse opinions, between positive short term possibilities and the perception that the contribution to the long term energy supply is irrelevant. With the present level of technology and market experience, the discussion should be able to move from fundamentally driven opinions towards a constructive and factual dialogue, involving different stakeholders and decision makers.

Defining adequate policy frameworks

A variety of policy initiatives have been developed over the past few years, both at the EC and Member State level. However, there are inconsistencies in policy objectives. The different policy approaches should be fully assessed and compared to allow lessons to be learnt and to ensure that the future European PV policy framework can be founded on quantitative and not qualitative arguments.

Approach

This document outlines, in broad terms, a strategic action plan necessary to achieve the vision. This action plan will need to be developed in the future in more detail, to better encompass what should be done, by whom and in what timeframe. The proposals presented here cover three main areas of intervention:

- Research and technology
- Industry
- Policy

To advance rapidly, these three areas should be connected more strongly than they are today, by the establishment of a PV Technology Platform. A strong connection is needed to accelerate the process because technology development is not a sequence of linearly connected activities, but rather a parallel process with pronounced interdependencies.

Table 4 classifies the key aspects of the research and technology, industry and policy areas in relation to stakeholder activities and interests. These intervention areas have different but complementary drivers.

---

[26] PVMAT: PV Manufacturing R&D Project (www.nrel.gov/pvmat)

Table 4: Classification of key aspects

	Research and technology	Industry	Policy
Actors	PV research community (universities, research institutes, private research) Materials science Electrical engineering Building research Storage technology Testing laboratories Standardisation bodies Socio-economic research community	PV industry PV supply chain PV installers Project developers Architects Utilities Building industry Finance sector	Policy-makers (energy, R&D, environment, development) Regulators Agencies Programme managers
Activities	Basic Research Applied research Product development Components Testing Development of harmonised measurements Monitoring Modelling	Industrial process development Manufacturing Product design Standards Project design Marketing Sales and after-sales Project implementation Maintenance Investment	Policy initiatives Policy debate Policy implementation Development of technology transfer infrastructure
Provider of	New materials, processes Scientific analysis New components Patents Validation Models Databases Standards Publications	Products Services Applications Projects Solutions Financing	Political goals International agreements Legislation Regulatory framework Public support Policy instruments Infrastructure, technology transfer centres
Drivers	Scientific understanding New technologies Scientific recognition	Successful projects Return on investments	Public welfare Political acceptance Sustainability

PV Technology Platform

A PV Technology Platform should be established, bringing together the relevant stakeholders from science, industry and policy. This platform can contribute directly to creating, implementing, supporting and stimulating a coherent and dynamic strategy for reaching the vision outlined in this document. The following stakeholders should be represented: industry, research institutions, energy companies, policy makers, NGOs (civil society), other professionals (architects, engineers, installers), financial actors, consumers associations, etc.

The establishment of a PV Technology Platform is a crucial strategic measure to support the achievement of the PV vision. Its role will be to fully define, support and accompany the implementation of a coherent and comprehensive strategic plan. It will:

- Mobilise all actors sharing a long-term European vision for PV
- Realise the European Strategic Research Agenda for PV for the next decade(s) and give recommendations for implementation
- Ensure Europe maintains industrial leadership.

More specifically, the PV Technology Platform will:

- Implement a strategic plan to provide advice and expertise to the decision makers to allow them to make informed decisions regarding the long term potential of PV
- Propose actions to all policy makers to help to ensure that clear, coherent priorities are established and that support is fully integrated, thereby facilitating implementation
- Foster joint initiatives involving stakeholders in the formulation of research programmes
- Ensure strong links and coordination between industry, research and market.

The PV Technology Platform should have a clear but flexible structure. The terms of reference should clearly describe the goals, the structure, the responsibilities and the working methods of the platform. It is suggested that a Steering Committee is established, comprising high-level decision makers from relevant stakeholder groups, to give the platform direction. The working groups (Figure 6) reflect the different sub-topics important for PV technology, and could be formed on an ad-hoc basis to respond to specific needs over time. A secretariat should also be established to facilitate the work of the platform. A Mirror Group would also ensure coordination with all national programmes, to provide a two-way interface between the activities of the platform and the public authorities responsible for PV research and dissemination programmes in the Member States.

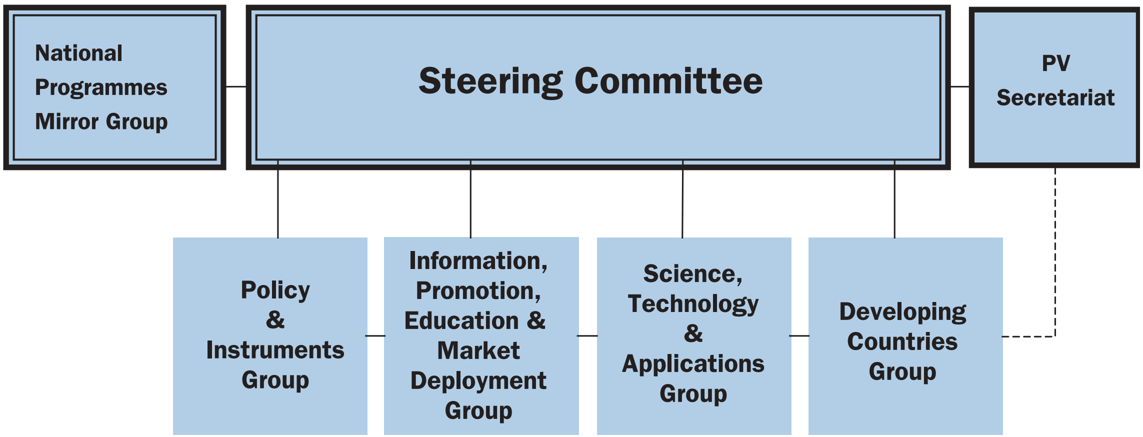
The strategic plan

The strategic plan should be organised along the following routes:

- Strategic Research Agenda
- Coordination of research programmes
- Implementation policies, creation of markets and support actions.

Only a strong European industry offering high-quality products at reasonable prices will be able to compete effectively in the PV market. The required continuous industrial investment will only be effective if backed by a coherent research and development programme and sufficient development of markets through a well-coordinated set of policies and support actions.

Figure 6: PV Technology Platform structure as proposed by PV-TRAC



The Strategic Research Agenda

The Strategic Research Agenda (SRA) describes the main research issues to be addressed in order to realise the vision. This SRA is neither a specific research programme nor a work programme. It is rather a set of principles, issues, requirements and research areas which should inspire all stakeholders when they develop their own activities or programmes in the PV research sector.

From the point of view of robustness of PV development, it is necessary to have a continuous development chain from basic research to industrial manufacturing. Basic research generates a range of options necessary in the long-term research agenda. Applied research focuses on the most promising options by critically assessing the potential in relation to industrial application. This comprises development of materials, devices and processes up to prototyping level. Knowledge has to be transferred rapidly and effectively to the manufacturers. In order to speed up the availability of mature and standardized production equipment, R&D on the industrial aspects should be supported. This will reduce capital costs per unit to keep the risk to the investor at a calculable and affordable level. Spin-offs and cross fertilization with other markets are important factors.

In order to maximise the environmental benefits of PV, particular attention should be paid to the environmental impacts of the various technology options, through the use of appropriate methods like integrated impact assessment and life-cycle analysis (from cradle to grave).

Research efforts should therefore encompass:

Basic research, focusing on promising materials, device concepts and conversion principles, whilst allowing some intellectual freedom to researchers

Applied research and development: results of the basic research should be critically assessed on their industrial potential, and materials and processes have to be transferred effectively and rapidly to a prototyping level according to manufacturing needs

Demonstration of innovative solutions for PV manufacturing and system integration

Supporting research, providing support in the socio-economic, standardization, quality assurance of systems (including safety aspects) and environmental areas.

Important subjects to be addressed also include:

- The need to develop European production of silicon feedstock
- The development of dedicated industrial manufacturing equipment instead of adaptation of laboratory equipment
- EU manufacturers' co-operation versus competition.

Research efforts should be geared towards very substantial price reductions such as the targets given in Table 5.

Table 5: Target prices up to 2030

Deadline	Module target price (€/W)	System target price (€/W)
2010	2	3
2020	≤1	2
2030	≤0.5	1

A tentative list of research areas, built on the basis of the Council's own analyses and priorities mentioned above is provided in the Appendix to this report. The main topics are the following:

- Current module technologies
- New and emerging module technologies
- Balance-of-system
- Building integration
- Systems aspects (storage, grid optimisation, etc.)
- Manufacturing issues
- Supporting research.

PV RTD programmes and coordination

PV in the Seventh Framework Programme (FP7): The PV Technology Platform will provide input and recommendations to the content and structure of FP7 relating to PV. In particular, the position of PV research in FP7 should be enhanced by:

- Taking full benefit of the newly proposed instruments (in particular the possibility of launching a Joint Technology Initiative should be explored)
- Allocating sufficient funds for PV research and demonstration and establishing a dedicated budget line for PV in FP7
- Working in full synergy with the instruments geared towards the European Research Area (ERA), possibly including EUREKA and COST initiatives.

PV RTD programme coordination: European and national PV research programmes have only been loosely coordinated and have different priority areas, approaches and procedures. The PV-ERA-NET project (a project funded under FP6) could be linked to the future PV Technology Platform. Furthermore, regular exchange with other international programmes and networks should be encouraged, notably the PV research programmes of the US and Japan as well as the IEA PVPS Programme.

Networks of excellence: Two areas may justify the setting-up of specific structures, possibly under the form of networks of excellence:

- Network of laboratories providing analytical and testing facilities as well as facilities for process development
- Constant assessment of the status of research activities and progress made, with a view to providing support to the PV Technology Platform and its members in the definition of research priorities.

Implementation policies and market creation

Policy framework: The sustained growth of the PV market requires a policy framework and regulations which account for the specific characteristics of PV. Unless the policy framework foresees technology-specific measures, PV will not be able to compete in the short term. The regulatory framework should not be seen merely as a basis for giving subsidies to an otherwise non-competitive technology, but rather as part of a policy which takes long-term responsibility for investing in a sustainable energy supply.

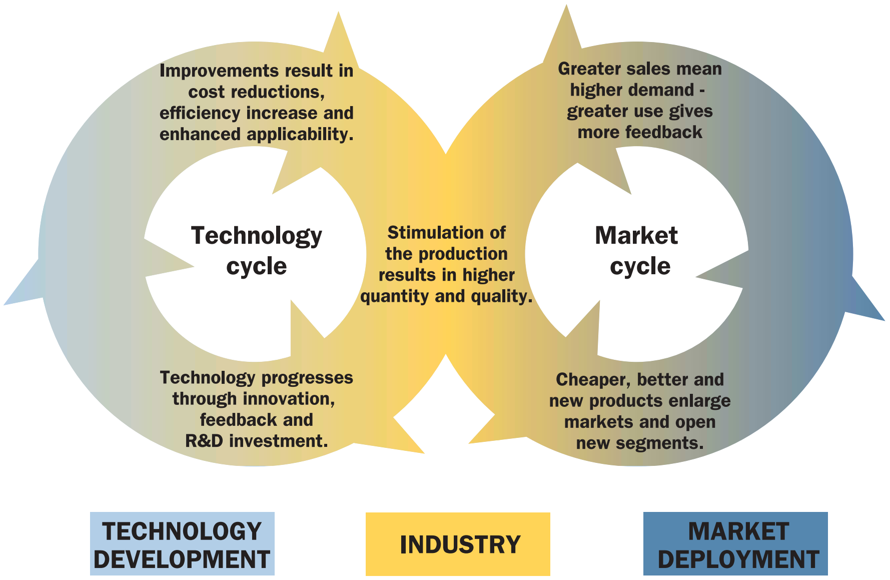
The policy framework for PV should be designed in such a way that it adopts a two-track approach, optimising both technology development and market support mechanisms. The relationship between technology development and market support mechanisms is not well understood, and requires assessment to ensure the balance of any measures introduced to produce maximum benefits.

With regard to market support mechanisms, as indicated earlier, the feed-in tariff as presently deployed in Germany and recently in Spain, is an effective means of stimulating the market. A European-wide feed-in tariff scheme, along the example of Germany, would increase the uptake of PV and help to achieve the transition towards a sustainable energy supply more rapidly; however, such an EU-wide scheme would take considerable time to be adopted and some countries may not be in favour. Under such circumstances, it is important to identify other options for a regulatory framework that would also favour the market deployment of PV.

The RES-e Directive has provided a framework of targets and support for the growth of the green electricity share in consumption since 2001.

In 2004, as required by the RES-e Directive, the European Commission produced an assessment of Member States progress towards the renewable energy targets and the implications for Europe. This assessment was published in May 2004 in the Communication ‘The share of renewable energy in the EU’[27], where the Commission also assessed the progress being made in achieving the general 2010 target of 12% in overall energy consumption. To accompany this communication, a document with the 25 Member States’ profiles and their RES situation has been issued[28].

Figure 7: Technology vs. market cycle



Source: NET/Switzerland

The assessment shows that four Member States (Denmark, Germany, Spain, and Finland) have actively adopted measures and are therefore on line to meet their renewable energy and green electricity commitments. For the rest of Europe the picture is not that optimistic; considering the policies and measures currently in place, EU-15 will probably achieve a share of only 18%–19% in 2010. Other Member States must act more quickly to introduce more ambitious policies in order to meet their targets.

A PV platform could provide a valuable means of establishing a well-balanced view, which is supported by all of the key stakeholder groups, concerning the potential of PV technologies and the most appropriate policies, regulations and targets needed for their future development.

In addition, the Commission intends, from 2004 onwards, to emphasise the deployment of renewable energy in its main financial instruments, the Structural and Cohesion Funds; this is also true for the relevant rural development measures, the second pillar of the common agricultural policy.

Developing countries: Strong dedicated effort is required to support the implementation of PV in developing countries. Stronger partnerships should, therefore, be developed between multilateral and bilateral donor agencies, including the European Commission, NGO's and the finance sector.

Export and trade: The development of PV as foreseen in the vision will lead to the establishment of a strong European industrial base. As the PV industry grows, the supply industry, export and trade will become increasingly important. Existing barriers to successful trade and export should be addressed on the global, EU and the national levels.

Education and training: For a successful implementation of PV, a strong effort is required in the field of education and training at all levels (from installation technicians to PhD students). This aspect should be elaborated further by the Platform.

Communication: A structured communication plan is essential to identify target audiences and means of communication, working in coordination with other existing information networks. The PV Technology Platform will be instrumental in proposing and implementing suitable communication mechanisms. A group has been proposed in the platform that could work in this direction.

---

[27] (1) COM(2004) 366 final, 26.5.2004: Communication from the Commission to the Council and the European Parliament 'The share of renewable energy in the EU'

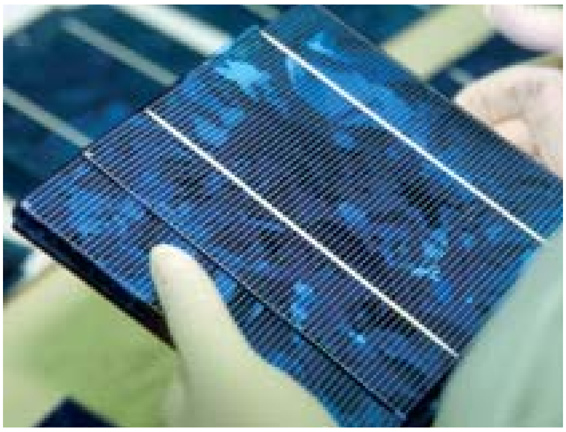
[28] (2) SEC(2004) 547, 26.5.2004: Commission staff working document 'The share of renewable energy in the EU – Country profiles – Overview of renewable energy sources in the enlarged European Union', available on the Internet (http://europa.eu.int/comm/energy/res/documents/index_en.htm)

MAIN RECOMMENDATIONS

Photovoltaics has the potential to play an important role in the transition towards a sustainable energy supply system for the 21st century, providing environmentally benign energy services, economic and social welfare and contributing to the security of future energy supplies. In combination with other renewable energy technologies and energy efficiency, photovoltaics can be seen as a **key technology** in the coming decades. Furthermore, PV is complementary to other major energy technology developments such as fuel cells and hydrogen, thereby further expanding its possible use.

In recent years, PV has enjoyed increasing market growth, and a 1 GW annual shipment capacity was reached in 2004. The industry base is growing rapidly, and becoming increasingly global, and the costs are constantly falling. Nevertheless, for PV to reach its foreseen role in the energy supply, research and technological development must continue, industry production must be ramped up substantially, costs must come down and sustainable markets must be created. All stakeholders should acknowledge the long-term strategic nature of developing PV for its future role and the need for action now.

In order to reach the PV vision, the Council advocates that a number of actions are taken, notably including the creation of a European PV Technology Platform. The PV Technology Platform is the preferred vehicle to mobilise and pursue PV-related initiatives, programmes and policies bringing together all relevant stakeholders from science, industry and policy areas. Implementation of the PV Platform will strongly increase the efficiency of the efforts currently underway and accelerate the development of the European PV sector. In particular, the Council recommends that the PV Technology Platform should:



- Implement the Strategic Research Agenda, in which the main PV research and technological development issues for the coming decade are addressed. To achieve the technology goals, research investment and continuity of effort are needed. PV research should be supported through both European and national funding mechanisms. The SRA should foster an interdisciplinary approach to the development of PV and cross-fertilisation from other rapidly developing fields.
- Strongly coordinate ongoing PV research activities in Europe with the help of a Mirror Group of all the Member States. European and national programmes should be reviewed to ensure stronger cooperation.
- Facilitate the coherent implementation of deployment measures (incentives, industrial, environmental, social and education). Promote, as a transitional measure over the next decade, a coordinated regulatory framework that takes the specific aspects of PV into account. Encourage a sustained growth and the transition to a sustainable market and overcome barriers related to regulations, standards, safety and social acceptance. The platform together with the Mirror Group will provide a mechanism for consensus building in these areas.
- Foster joint initiatives between researchers, industry, Members States and the EU. Develop a robust communication plan, as part of a continuous dialogue involving a broad range of stakeholders.
- Optimise the use of instruments and resources to encourage investment in research and innovation to capitalise on Europe’s investments for the PV sector, by supporting export and trade in PV products in the global marketplace.
- Strengthen the relationships with developing countries in order to bring affordable electricity services to the populations of these countries.

APPENDIX

Tentative list of research areas to be covered when implementing the Strategic Research Agenda

Current PV technologies

Wafer-based crystalline silicon technologies

Materials

- Availability, quality and price of silicon feedstock (including the development and understanding of solar grade silicon)
- Wafer equivalents for epitaxial cell structure approaches (this also implies reactor development for high-throughput epitaxial deposition)
- Substitution of critical materials, for cost (silver) or environmental (lead, etc.) reasons and design for recycling.

Equipment

- Crystallisation and wafer manufacturing processes (including ribbons) for strongly reduced silicon and energy use per watt
- Development of lower cost, standardised, fully automated process equipment.

Device concepts and processes

- Optimisation of processes developed originally for laboratory uses – adaptation to industrial scale;
- Process development for thin and/or large area wafers, including low waste processes
- Reduction of the energy consumption of processes (including feedstock production)
- New module designs for easy assembly, low cost and 25-40 years lifetime
- Advanced cell designs and processing schemes for high efficiencies (up to 22% on a cell level, 20% on a module level).

Thin-film technologies

Materials and devices

- Increase of module efficiencies from the current 5-12% to >15%
- Understanding of fundamental properties of materials and devices, especially interfaces
- Development of new multijunction structures
- Development of low-cost, high-performance TCO materials for thin-film cell designs
- Reduced materials consumption (layer thickness and yield), use of low cost, low-grade materials
- Reduction or avoidance of the use of critical materials, substitution of scarce or hazardous materials and recycling options
- Alternative module concepts (new substrates and encapsulation)
- Ensuring stable module operation for 20 to 30 years with less than 10% efficiency decrease.

Processes and equipment

- Development of processes and equipment for high yield, low-cost, large-area manufacturing
- Ensure the uniformity of film properties over large areas and understand the efficiency gap between laboratory cells and large area modules
- Increase stability of the process and yield
- Development of process monitoring
- Adopt successful techniques to industrial conditions in view of productivity and labour
- Reduction of energy pay-back-time of modules (from present 1.5 years to 0.5 years for central European climatic conditions).

Highly efficient cells for use in concentrators and for space applications

Multijunction compound semiconductor cells

- Increase efficiency from 40% to 50%
- Reduce manufacturing costs
- Optimise cells for space applications (thin-film, reduced weight, AM0 operation).

Silicon cells

- Development of designs for concentrator systems, including advanced design concepts.

New and emerging technologies

This area requires fundamental research because reaching the targets requires a thorough understanding of the underlying chemistry, physics and materials properties.

Sensitised-oxide-based and other nanostructured solar cells and modules

Organically sensitised cells and modules:

- Stability (from months or a few years (estimated) to >10 years)
- Efficiency (from 5 to 10% for modules)
- Fully solid state devices.

Inorganically sensitised cells (extremely thin absorber cells), ETA

- Efficiency (from very low to 5-10%).

Other nanostructured devices with potential for very low cost

- Efficiency (from very low to 5-10%).

Polymer and molecular solar cells

- Efficiency (from 3-5 to 10%)
- Stability (from very low to >10 years).

Development of stable, high-quality transparent conductor and encapsulant materials

Novel conversion concepts for super-high efficiency and full spectrum utilisation

- Spectrum conversion
- Multiband semiconductors
- Hot-carrier devices.

Cells for low light level applications

- Device designs for integration
- Use of flexible, low-cost substrates
- Ultra low-cost approaches.

Balance-Of-System (BOS)

In order to meet the system price targets, research on BOS issues is also very important, since substantial cost reductions are required.

Grid-connected PV systems

Power conditioning and interconnection

- Inverter design and manufacturing concepts aimed at low cost (£0.25 €/W) combined with excellent reliability and long lifetime (20 years+)
- Innovative module-integrated electronics for power conditioning, monitoring and control
- Design of multifunctional low-cost grid interfaces to ensure safe and reliable system operation.

Grid integration aspects

- New concepts for stability and control of electrical grids at high penetration levels of PV to ensure that networks are operated effectively and economically
- Control and communication strategies and interfaces for PV systems, including energy storage
- Development of power electronics to improve power quality at high penetration levels of PV
- Interactive energy management systems for optimisation of the value of PV electricity in grid-connected systems (including supply/demand matching).

Concentrator systems

- Low-cost, high-efficiency optical systems for high and low concentration factors, including compact, ultra-thin options
- Reliable, low-cost tracking systems.

Stand-alone PV systems: *Aimed at improved system reliability, lifetime and applicability as well as an improved life-cycle environmental profile.*

Components

- Theft protection for PV modules at risk of theft
- New power electronics and control devices, allowing for flexible system reconfiguration and growth
- Improved energy storage in the form of robust battery designs, charging strategies, algorithms, etc.

Systems technology

- Energy management of complex (hybrid) multi-user systems, billing and customer management systems, all being well adapted to the respective business models that have been proven suitable for the given local conditions and the cultural context
- Integration of these functionalities into power electronic components.

Socio-economics

- R&D on specific local and regional solutions for capacity building, business and financing models etc as a vital pre-requisite for successful implementation.

Building integration

Although strictly speaking an aspect of BOS, integration of PV into buildings and other objects is considered a research topic on its own because it requires the involvement of other stakeholder groups such as architects. Areas to be addressed concern the following:

Building integration and mechanical mounting of modules

- Options for reduced materials and labour costs
- Options for increased installation safety, easy repair and replacement.

Combination and integration of functions

- PV & shading, PV/thermal systems, ventilation, etc.

Total energy concepts.

Manufacturing issues

The lack of availability of dedicated processes and equipment for high-throughput manufacturing of PV components is a major barrier towards cost reduction and quality improvement. Issues to address include:

- In-line processes and equipment for thin, large-area crystalline silicon cells and the corresponding modules
- Advanced concepts and equipment for handling and logistics
- High throughput and yield, large-area deposition systems for thin-film solar modules
- Process and equipment innovations to reduce energy and materials consumption in manufacturing
- Standardisation of equipment
- In-process quality control and feedback systems;
- Manufacturing and assembly equipment for concentrator PV (adapted from electronics and optics industry)
- Development of low-cost, highly reliable and efficient optical and mechanical components for concentrator applications, including operation and maintenance schemes.

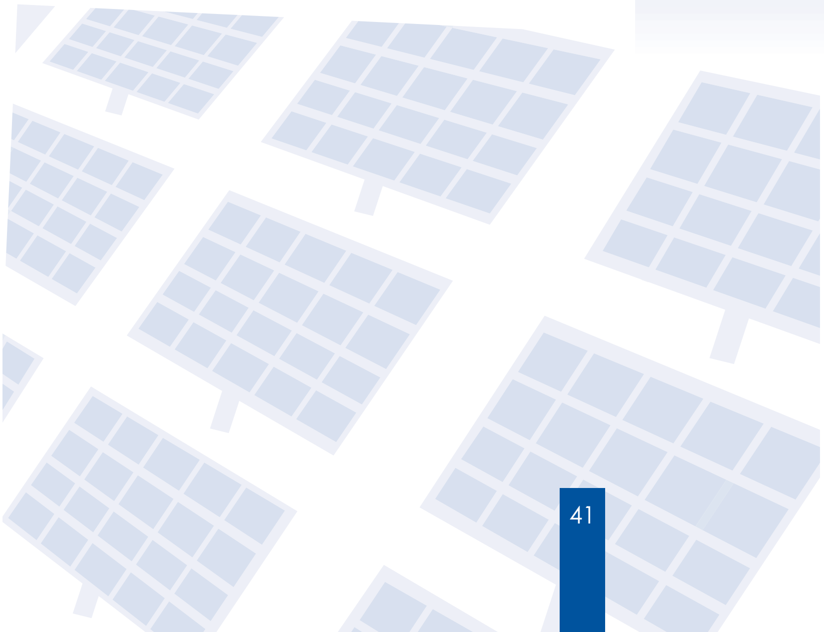
Supportive research

It is essential that other issues be properly (and in some cases much more aggressively) addressed:

Quality assurance and standardisation
These issues have been largely neglected which has caused a threat to the rapid development of PV. “Standardisation” refers to module-features, mounting techniques and electrical aspects, etc. The development of faster and lower cost qualification tests should be addressed.

Environmental aspects
The drive towards low cost and high efficiency does not yet lead to an optimum environmental profile. Replacement of critical materials with environmentally benign alternatives should be assessed in order to maximise the environmental benefits of PV. Life-cycle analyses and integrated impact assessments should be promoted.

Socio-economic research
Financial support to bring the sector to maturity needs consideration in relation to added benefits, such as the creation of jobs. Social acceptability, awareness raising, and cost/regulatory issues should also be addressed.



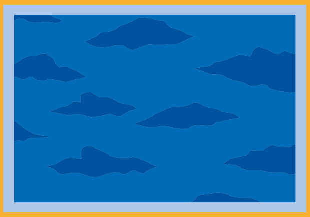
European Commission

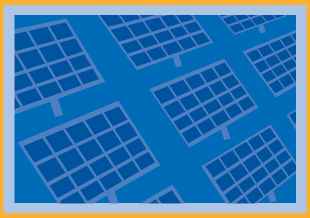
EUR 21242 – A Vision for Photovoltaic Technology

Luxembourg: Office for Official Publications of the European Communities

2005 – 41 pp. – 21.0 x 29.7 cm

ISBN 92-894-8004-1





This report by the Photovoltaic Technology Research Advisory Council (PV-TRAC) reviews the current status of photovoltaics, a technology which provides renewable solar electricity, and presents a vision of photovoltaic technology for 2030 and beyond. The Advisory Council recommends the creation of a European Technology Platform and the implementation of a Strategic Research Agenda. This publication is a valuable tool for all stakeholders in the sector to ensure that efficient and coordinated actions are taken, at both national and European levels, to enable photovoltaics to reach its full potential in the sustainable energy portfolio of the future.

A preliminary version of the report was presented and discussed at the conference "Future Vision for PV" in Brussels on 28 September 2004.

15
KI-NA-21-242-EN-C

ISBN 92-894-8004-1

Publications Office
Publications.eu.int